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The Role of Burst Pressure Relationship within VVER Steam Generator Structural Integrity Assessment and its Determination

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Preliminary note

The main task of every nuclear power plant owner is to establish the balance in taking precautions such as monitoring, inspection and corrective actions, with the aim of retaining the steam generator integrity. The steam generator integrity assessment presents the key factor in achieving the mentioned aim. It is necessary to conduct a wide range of researches for a quality of steam generator integrity assessment. One of the key elements as well as starting point for steam generator structural integrity assessment is establishing burst pressure relationship for each degradation mechanism orientation, type and their location on steam generator tubes. This paper presents the role of burst pressure relationship within VVER steam generator structural integrity assessment and its determination. In addition to this, the results of researches for the axially oriented flaws on the free span will be presented, with the aim of establishing burst pressure relationship.

Uloga ovisnosti tlaka pucanja i strukturne varijable u procjeni strukturnog integriteta cijevi parogeneratora VVER-tipa i njeno određivanje

Prethodno priopćenje

Osnovna zadaća svakog vlasnika elektrane je uspostaviti ravnotežu u poduzimanju preventivnih mjera kao što su praćenje, ispitivanje te korektivne akcije u cilju očuvanja integriteta cijevi parogeneratora. Procjena integriteta cijevi parogeneratora predstavlja ključni čimbenik u ostvarenju navedenog cilja. Potrebno je provesti široki spektar istraživanja za kvalitetnu procjenu integriteta cijevi parogeneratora. Jedan od ključnih elemenata, ali i polazišna točka u procjeni strukturnog integriteta cijevi parogeneratora je uspostavljanje relacijske ovisnosti tlaka pucanja i strukturne varijable za svaki oblik, vrstu i mjesto pojavljivanja degradacijskog procesa na cijevima parogeneratora. Ovaj članak opisuje ulogu ovisnosti tlaka pucanja i strukturne varijable u procjeni strukturnog integriteta cijevi parogeneratora VVER-tipa kao i njeno određivanje. Prikazat će se i rezultati istraživanja za slučaj aksijalno orijentiranih oštećenja na slobodnoj duljini cijevi s ciljem uspostavljanja relacijske ovisnosti tlaka pucanja i strukturne varijable.

1. Introduction

Steam generator is one of the most important components of nuclear power plants regarding functionality and safety. Steam generator tube damage can impair the safety of nuclear power plant operation. Main requirement during nuclear power plant operation, that arises from the safety requirements, is the retaining of the integrity of the primary circuit, thus a steam generator in its entirety. Structural integrity assessment (SIA) implies the evaluation whether the tube can withstand the operating condition reliably and safety during the lifetime. The SIA shall demonstrate that the tube integrity will be retained during the next operating interval under normal and accidental condition that may occur. If the tube integrity cannot be retained then the tube shall be remove from the service by plugging.

SIA for VVER nuclear power plants have not been performed yet. Therefore, it is necessary to conduct a series of analysis, research to establish a basis for VVER structural integrity assessment development. This is a comprehensive and complex task that shall consider:

- Establishment of burst pressure and structural variable relationship for each degradation mechanism orientation. Defects are classified into three categories based on their morphology: axial, circumferential and volumetric. Structural variable is dependent on depth, length or voltage.
- Consideration of each uncertainty having an influence on the structural integrity such as: relational, material property, NDE uncertainty. NDE uncertainty implies eddy current technique used for determining the tube condition.

Symbols/Oznake

P_B	- burst pressure, bar - tlak pucanja	Z	- random variable - - slučajna varijabla
S	- structural variable - strukturna varijabla	$EFPY$	- effective full power year - efektivan broj godina pri punoj snazi rada
S_v	- yield strength, bar - čvrstoća na granici elastičnosti	h_{growth}	- depth growt - porast dubine oštećenja
S_u	- ultimate strength, bar - čvrstoća na granici loma	σ_m	- material property uncertainty, bar - neodređenost svojstava materijala
t	- wall thickness, mm - debljina stijenke	σ_L	- degradation length measurement uncertainty, - neodređenost mjerenja duljine oštećenja
R_i	- inner radius, mm - unutarnji radijus	σ_h	- degradation relative depth uncertainty - neodređenost relativne dubine oštećenja
L	- degradation length, mm - duljina oštećenja	σ_r	- relational uncertainty, bar - relacijska neodređenost
h	- relative degradation depth - relativna dubina oštećenja		

2. Tables and table captions

3. Basic methodology

The structural integrity assessment process implies comparison of the structural capacity of the degraded tube with structural integrity performance criterion. The structural capacity of the tube is represented by the burst pressure relationship (Figure 1) which describes burst pressure as a structural variable function. The burst pressure relationship is established as the mean regression of the experimentally acquired data by performing burst test on the degraded tubes. The structural limit is defined by appropriate structural parameter such as loss of wall thickness, degradation length or volume that can be measured by eddy current.

The structural limit is determined by the intersection of the burst requirement line and the burst pressure curve. The burst requirement line in Figure 1 represents the structural integrity performance criterion, three times the normal operating pressure differential across the tube wall. The obtained structural limit is the value below which the structural performance criterion is met meaning if the structural limit is below the structural variable then the tube shall be plugged, otherwise it remains in-service. The projected flaw size of the undetected flaws and/or detected flaws intentionally left in service shall not exceed the repair limit. It is necessary that flaws remaining in service at the beginning of cycle meet the structural integrity performance criterion over the full length of the ensuing cycle. Determination of the repair limit includes burst pressure relationship, relational uncertainty, tube

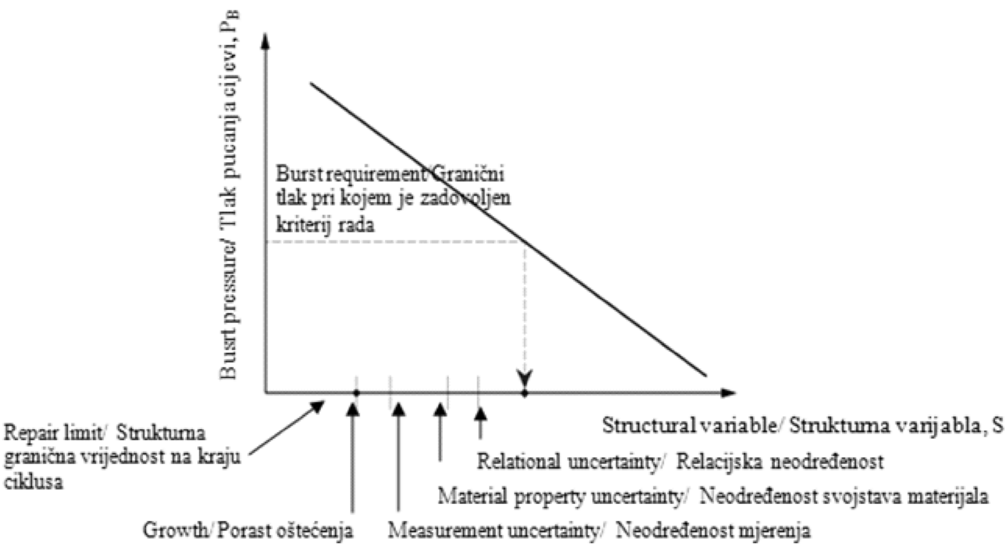

Figure 1. Elements for determining repair limit

Slika 1. Elementi za određivanje strukturne granične vrijednosti na kraju ciklusa material strength, material property uncertainty, NDE measurement uncertainty, degradation growth during the operation and associated growth uncertainty (Figure 1).

4. Tubes with axially oriented flaws

Burst pressure relationship as the starting point for identifying repair limit as shown in Figure 1, is experimentally determined. For that purposes, ten tubes were undergone to the laboratory testing, nine out of ten with various degradation length and depth in order to obtain the impact of each parameter. Samples are prepared in accordance with the procedure. Figure 2 represents the sample before the burst test and Figure 3 tube sample after the burst test.

Figure 2. Defected tube before burst test

Slika 2. Cijev s oštećenjem prije tlačnog testa

Figure 3. Defected tube after burst test

Slika 3. Cijev s oštećenjem poslije tlačnog testa

Information on tubes with defects, axially oriented, material 08X18H10T and the outcomes of the burst test are presented in Table 1. The outer diameter of each tube sample is 16 mm, and the tube thickness is 1.5 mm. The degradation depth is presented as the percentage of loss of wall thickness.

The burst pressure equation (1) is a semi-empirical relationship based on burst test data. The burst pressure is a function of structural degradation depth, h, and degradation length, L.

The value of factor K is K=0.52. In order to determine the value of factor K, among the burst test, it was necessary to determine the value of yield strength as well as ultimate material strength. For that purposes, experimental research was conducted on sixteen samples, material 08X18H10T at room temperature as well as operating temperature.

Burst pressure equation (1) enables us to determine the structural limit by meeting the burst requirement, 3ΔP. The structural limit is in a function of degradation length, L and degradation depth, h.

Use of a structural limit minus allowances for relational uncertainty, material property uncertainty, NDE measurement uncertainty and growth of degradation permits determination of a repair limit.

The equation (2) involves above listed parameters and provides us to determine the repair limit

$$P_{\mathrm{B}} = K \cdot \left(S_{\mathrm{y}} + S_{\mathrm{u}}\right) \cdot \frac{t}{R_i} \cdot \left(1 - 0.015 \cdot \frac{L}{t} - 0.741 \cdot h^2\right), \qquad (1)$$

$$P_{\mathrm{B}} = K \cdot \left(S_{\mathrm{y}} + S_{\mathrm{u}} - Z\sigma_{\mathrm{m}}\right) \cdot \frac{t}{R_i} \cdot \left(1 - 0.015 \cdot \frac{\left(L + Z\sigma_{\mathrm{L}}\right)}{t} - 0.741 \cdot \left(h + Z\sigma_{\mathrm{h}} + h_{\mathrm{porast}}\right)^2\right) - Z\sigma_{\mathrm{r}}. \qquad (2)$$

Table 1. Tube sample description with axially oriented defects, 08X18H10T, and the burst test results

Tablica 1. Podaci o uzorcima s oštećenjima aksijalno orijentiranih, 08X18H10T, i rezultati tlačnog testa

Sample identification / Oznaka uzorka	Defect dimension/ Dimenzija oštećenja			Burst pressure, bar / Tlak pucanja, bar
	Length / Duljina, mm	Width / Širina, mm	Depth / Dubina, %	
AB 00 00	0	0	0	1308.05
AB 10 80	10	0.2	80	613
AB 15 80	15	0.4	78.67	549.84
AB 20 40	20	0.4	39.33	939.40
AB 20 60	20	0.4	58.67	740.20
AB 20 70	20	0.4	68	569.46
AB 20 80	20	0.4	78	468.24
AB 20 90	20	0.4	88	280.20
AB 25 80	25	0.4	78	426.48
AB 30 80	30	0.4	78.67	348.24

5. Conclusion

Structural integrity assessment is demanding and complex process. It relies on determining the repair limit, detecting and sizing the tube degradation. Therefore, the primary task is to establish burst pressure relationship and precisely determine parameters such as relational uncertainty, material property uncertainty, NDE measurement uncertainty, growth rate and associated uncertainty in order to define the repair limit.

NDE plays significant role within structural integrity assessment as it is described by the capability to precisely measure the size and detect flaws. Applying the appropriate technique will result in quality picture of tube condition, present degradation mechanisms, their location, size and orientation and detection of degradation.. Thus, analyst education, training and experience are essential for the structural integrity assessment.

Successful implementation of the integrity assessment will help ensure that the steam generator is maintained properly over normal operating condition, as well as accidental conditions that might occur in the ensuing cycle.

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